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Richness and abundance of arthropods in the oak canopy of West Virginia's eastern ridge and valley section during a study of the impact of Bacillus thuringiensis with emphasis on macrolepidoptera larvae

Linda Butler

Cathy Zivkovich

Bradley E. Sample

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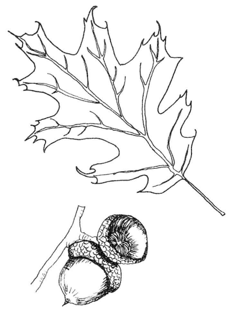

The Authors

Linda Butler and Cathy Zivkovich[1]
Division of Plant and Soil Sciences, West Virginia University
and
Bradley E. Sample[2]
Division of Forestry, West Virginia University

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[1]We dedicate this paper to our friend and colleague Cathy Zivkovich who died February 16, 1995. We miss her.

[2]Current address: Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831 (Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy).

West Virginia University
Agricultural and Forestry Experiment Station
College of Agriculture and Forestry
Rosemary R. Haggett, Director
Morgantown

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Linda Butler and Cathy Zivkovich
Division of Plant and Soil Sciences, West Virginia University
and
Bradley E. Sample[1]
Division of Forestry, West Virginia University

Introduction

Since its introduction into Massachusetts in 1869, gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae) has spread widely and become the most serious defoliator of deciduous trees in the eastern United States. Aerial insecticide applications, particularly diflubenzuron (Dimilin®) and the bacterial insecticide *Bacillus thuringiensis* var. *kurstaki* (*Btk*) are prominent methods for managing gypsy moth larvae.

Bacillus thuringiensis is a spore-forming bacterium that produces a crystalline toxin during sporulation. *Bt* var. *kurstaki* is toxic primarily to larvae of Lepidoptera (Boberschmidt et al. 1989). While the mode of action of *Btk* gives it considerably more specificity than the more broad spectrum diflubenzuron (Martinat et al. 1988, 1993; Sample et al. 1995; Butler 1995), non-target Lepidoptera (i.e. species not intentionally targeted) are directly susceptible to *Btk* (Miller 1990 a, b). Indirect effects also have been evaluated on parasitic wasps and flies, mortality resulting when *Btk* kills the host of the parasitoids (Reardon et al. 1979).

Baseline studies of communities of canopy arthropods in West Virginia were begun in 1983 with greatest emphasis on abundance and richness of larvae of macrolepidoptera (Butler 1992). In this context, abundance refers to total numbers of larvae while richness indicates number of species. These studies were stimulated in large part by the need to document structure of canopy arthropod communities prior to potential alterations of those communities by gypsy moth defoliation or suppression programs. A two-year study at Coopers Rock State Forest (1983, 1984) indicated a diverse and abundant community of caterpillars on hardwood foliage (Butler 1992).

Between 1990 and 1992, we evaluated the impact of *Btk* on all arthropods of oak canopies in Grant and Pendleton counties in West Virginia's Eastern Ridge and Valley Section. Evaluation of impact to the caterpillar community comprised a large portion of that study. We have presented the results of that study as richness and abundance within arthropod taxa on foliage of *Btk*-treated and untreated plots (Sample et al. 1995). Here we present macrolepidoptera larval species and other arthropods on oak foliage for 1990-1992 for treated and untreated plots.

Materials and Methods

From 1990 to 1992 data were collected from 24 plots located in the Ridge and Valley region of Grant and Pendleton counties. This area is predominantly forested in oaks (*Quercus* spp.), hickories (*Carya* spp.) and pines (*Pinus* spp.) with a sparse understory of mountain laurel (*Kalmia latifolia* L.) and blueberry (*Vaccinium* spp.). Each of the 24 plots was 20 hectares (50 acres) in size and situated at elevations from 350 meters to 1150 meters. Similarity of plots was compared by performing vegetation analysis after the method of James and Shugart (1970).

Pretreatment baseline data on foliage arthropod richness and abundance were collected on all plots in 1990. Six plots were sprayed with *Btk* on May 8, 1991 and six plots on May 10, 1991. *Btk* was applied as Foray 48B undiluted at a rate of 7.0 L formulation per hectare (96 oz./acre). A single application of *Btk* was made by helicopter at 15 Billion International Units (BIU)/ha (36 BIU/acre). The remaining 12 plots served as untreated controls.

Each week from mid-May to early August 1990, 1991 and 1992 20 to 25 branch tips of foliage of various oak species were taken from low-to mid-canopy with pole pruners from two randomly located sites within each of the 24 plots in order to evaluate presence of arthropods in the canopy. Pole pruners were equipped with large plastic catch bags to catch the foliage samples that fell. Following collection, all foliage samples were returned to the laboratory where all arthropods were removed from leaves and stems of the sample; macrolepidopterous larvae were identified to species and other taxa to family or superfamily. Foliage was removed from branch tips, oven dried at 65°C, weighed and the numbers of arthropods quantified per 50 g dry foliage weight.

Since the 24 study plots were located in an area of West Virginia with building gypsy moth populations, *Lymantria dispar* larvae were present on plots and four of the 12 untreated plots showed defoliation of 40% or more during one or two of the study years. We have evaluated the significance of the defoliation elsewhere (Sample et al. 1995).

Also notable were the differences in weather patterns among the study years. Mean April-August temperatures were greatest in 1991 (mean = 20°C, SE = 0.09°C), intermediate in 1990 (mean = 18.3°C, SE = 1.1°C) and least in 1992 (mean 16.1°C, SE = 1.3°C). While mean April-August precipitation was least in 1991 (mean = 6.1 cm, SE = 0.7 cm), there was no difference between the mean April-August precipitation for 1990 and 1992 (1990: mean = 7.6 cm, SE = 1.1 cm; 1992: mean = 8.3 cm, SE = 0.8 cm). Weather factors are known to exert considerable influence on insect populations (Uvarov 1931).

Voucher specimens from the study are deposited in the WVU Arthropod Collection. Species are named and listed after the checklist given by Hodges et al. (1983).

Results

Richness and abundance for nontarget macrolepidopterous larvae (i.e. species other than gypsy moth larvae) on untreated and *Btk*-treated plots are given for 1990 through 1992 (Table 1). In 1990, the pretreatment year, species richness was similar on control (67 species) and treated plots (64 species). Total nontarget macrolepidoptera larval richness declined to 29 species on the *Btk*-treated plots in the treatment year (as compared to 46 species on control plots) but was slightly greater on the treated plots than the control plots in the post-treatment year.

Table 1. Richness and abundance of nontarget macrolepidoptera larvae in the oak canopy on *Bacillus thuringiensis* - treated (T), and control (C) plots.[1]

Plots	Year	Richness	Abundance
C	1990	67	1,086
T	1990	64	739
C	1991	46	294
T	1991	29	148
C	1992	33	113
T	1992	38	116
Total Richness, Abundance		91	2,496

[1]Bt was applied in May, 1991

Abundance of nontarget macrolepidoptera larvae was 32% greater on control plots in the pretreatment year, 50% greater in the treatment year, and 2.5% less in the post-treatment year. It is noted that abundance declined dramatically over the three years of the study even on the control plots, from 1086 in 1990, to 294 in 1991 and 113 in 1992.

All macrolepidoptera larvae collected during the study are listed in Table 2. Total species richness is 91, representing 10 families. In addition to yearly totals for treated and control plots and totals for the entire study, we give the earliest and latest dates of collection and the date of peak collection for each species.

Table 2. Species of macrolepidopterous larvae collected from foliage of mixed oak species: first and last collecting dates of the combined sampling years of 1990-1992, number per year for treated (T) and control (C) plots and total number for the study.

Species*	*Collection Dates* First - Last	Peak	T90	C90	T91	C91	T92	C92	Total
HESPERIIDAE									
Erynnis juvenalis (F.)	13 May - 10 Aug	08 Jul	5	2	2	4	1	2	12
LYCAENIDAE									
Satyrium falacer (Godt.)	13 May - 04 Jun	20 May	5	5	1	1	1	0	11
NYMPHALIDAE									
Basilarchia archippus (Cram.)*	13 May - 13 May	13 May	0	0	0	2	0	0	2
GEOMETRIDAE									
Alsophila pometaria (Harr.)	13 May - 15 Jun	26 May	3	13	1	9	1	13	40
Hypomecis umbrosaria (Hbn.)	23 Jul - 23 Jul	23 Jul	1	0	0	0	0	0	1
Iridopsis larvaria (Gn.)	02 Jul - 02 Jul	02 Jul	0	1	0	0	0	0	1
Anavitrinella pampinaria (Gn.)	26 May - 20 Jul	20 Jul	0	0	1	0	0	2	3
Cleora sublunaria (Gn.)*	25 Jun - 25 Jun	25 Jun	0	1	0	0	0	0	1
Protoboarmia porcelaria (Gn.)	04 Jun - 04 Jun	04 Jun	0	2	0	0	0	0	2
Melanolophia canadaria (Gn.)	13 May - 12 Aug	11 Jun	7	5	2	7	1	1	22
Melanolophia signataria (Wlk.)	29 May - 29 May	29 May	1	0	0	0	0	0	1
Biston betularia (L.)	24 Jun - 20 Jul	20 Jul	0	0	0	1	1	0	2
Hypagyrtis unipunctata (Haw.)	13 May - 13 Aug	14 May	10	21	0	7	3	0	41
Phigalia titea (Cram.)	13 May - 22 Jun	29 May	36	103	1	31	1	0	172
Phigalia strigataria (Minot)*	13 May - 04 Jun	29 May	13	26	4	13	4	5	65
Erannis tiliaria (Harr.)	13 May - 18 Jun	21 May	84	153	1	24	0	1	263
Nacophora quernaria (J.E. Smith)	10 Jun - 13 Aug	09 Jul	4	5	0	1	0	0	10
Campaea perlata (Gn.)	10 Jun - 12 Aug	15 Jul	3	3	2	3	0	1	12
Ennomos subsignaria (Hbn.)*	20 May - 16 Jul	20 May	7	4	1	3	1	1	17
Plagodis serinaria (H.-s.)	25 Jun - 25 Jun	25 Jun	0	1	0	0	0	0	1

Species*	Collection Dates First	Collection Dates Last	Peak	T90	C90	T91	C91	T92	C92	Total
GEOMETRIDAE										
Plagodis alcoolaria (Gn.)	25 Jun	25 Jun	25 Jun	0	1	0	0	0	0	1
Besma endropiaria (G. & R.)	24 Jun	13 Aug	29 Jul	3	5	13	12	2	4	39
Besma quercivoraria (Gn.)	26 May	13 Aug	26 May	14	11	0	6	2	3	36
Lambdina fiscellaria (Gn.)*	29 May	12 Aug	06 Aug	7	2	3	1	1	0	14
Tetracis cachexiata (Gn.)	26 May	13 Aug	25 Jun	5	2	1	0	0	1	9
Eutrapela clemataria (J.E. Smith)	14 May	11 Jun	04 Jun	6	1	0	0	0	0	7
Nemoria lixaria(Gn.)*	18 Jun	12 Aug	16 Jul	2	2	0	1	0	0	5
Hydriomena divisaria (Wlk.)*	14 Jul	10 Aug	22 Jul	0	0	0	5	2	6	13
Eupithecia miserulata (Grt.)	30 Jul	30 Jul	30 Jul	1	0	0	0	0	0	1
Eupithecia herefordaria (C. & S.)*	04 Jun	25 Jun	25 Jun	2	1	0	0	0	0	3
LASIOCAMPIDAE										
Tolype velleda (Stoll)*	03 Aug	03 Aug	03 Aug	0	0	0	0	1	0	1
Malacosoma disstria (Hbn.)	26 May	17 Jun	29 May	4	2	0	2	1	1	10
SATURNIIDAE										
Anisota senatoria (J.E. Smith)	16 Jul	13 Aug	23 Jul	134	265	0	0	0	0	399
Anisota virginiensis (Drury)	16 Jul	12 Aug	30 Jul	3	46	27	0	0	0	76
Hemileuca maia (Drury)*	04 Jun	02 Jul	04 Jun	37	3	0	0	1	0	41
Antheraea polyphemus (Cram.)	06 Aug	06 Aug	06 Aug	1	0	0	0	0	0	1
Hyalophora cecropia (L.)*	23 Jul	23 Jul	23 Jul	0	1	0	0	0	0	1
NOTODONTIDAE										
Nadata gibbosa (J.E. Smith)	11 Jun	13 Aug	05 Aug	25	20	16	5	5	4	75
Hyperaeschra georgica (H.-S.)	13 May	10 Aug	13 May	2	0	0	3	2	0	7
Peridea angulosa (J.E. Smith)	27 Jul	13 Aug	13 Aug	0	1	0	0	0	1	2
Symmerista albifrons (J.E. Smith)*	10 Aug	10 Aug	10 Aug	0	0	0	0	22	0	22
Macrurocampa marthesia (Cram.)	24 Jun	13 Aug	13 Aug	5	7	3	4	3	2	24
Heterocampa guttivitta (Wlk.)	25 Jun	23 Jul	16 Jul	1	6	0	0	0	0	7
Lochmaeus manteo (Doubleday)	30 Jul	13 Aug	12 Aug	5	1	5	4	0	0	15
Schizura unicornis (J.E. Smith)	27 Jul	27 Jul	27 Jul	0	0	0	0	0	1	1

Species*	Collection Dates First - Last	Peak	T90	C90	T91	C91	T92	C92	Total
ARCTIIDAE									
Hyphantria cunea (Drury)	14 May - 12 Aug	12 Aug	5	4	9	7	0	1	26
Halysidota tessellaris (J.E. Smith)	08 Jul - 13 Aug	13 Aug	8	17	2	3	0	0	30
LYMANTRIIDAE									
Dasychira dorsipennata (B. & McD.)	14 May - 14 May	14 May	1	0	0	0	0	0	1
Dasychira basiflava (Pack.)	28 May - 13 Aug	06 Aug	6	5	3	2	0	0	16
Dasychira obliquata (G. & R.)	14 May - 10 Aug	29 May	2	2	0	1	1	0	6
Orgyia leucostigma (J.E. Smith)	15 Jun - 15 Jun	15 Jun	0	0	0	0	0	1	1
Lymantria dispar (L.)	13 May - 03 Aug	13 May	88	422	15	724	127	704	2080
NOCTUIDAE									
Bomolocha baltimoralis (Gn.)	24 Jun - 22 Jul	24 Jun	0	0	1	1	0	0	2
Panopoda rufimargo (Hbn.)	06 Aug - 06 Aug	06 Aug	1	0	0	0	0	0	1
Phoberia atomaris (Hbn.)*	13 May - 11 Jun	29 May	5	5	1	2	2	0	15
Zale minerea (Gn.)	29 May - 15 Jun	29 May	2	1	0	1	1	1	6
Zale lunifera (Hbn.)	11 Jun - 11 Jun	11 Jun	0	1	0	0	0	0	1
Catocala ilia (Cram.)*	14 May - 14 May	14 May	0	1	0	0	0	0	1
Catocala micronympha (Gn.)*	21 May - 21 May	21 May	2	0	0	0	0	0	2
Catocala amica (Hbn.)*	13 May - 22 Jun	21 May	6	10	0	4	1	1	22
Meganola minuscula (Zell.)*	25 Jun - 09 Jul	25 Jun	1	1	0	0	0	0	2
Meganola spodia (Franclemont)*	13 May - 29 May	13 May	1	1	0	4	0	0	6
Hyperstrotia secta (Grt.)*	23 Jul - 13 Aug	30 Jul	4	1	0	0	0	0	5
Colocasia propinquilinea (Grt.)	28 May - 28 May	28 May	0	0	0	1	0	0	1
Acronicta lobeliae (Gn.)*	25 Jun - 30 Jul	25 Jun	2	2	0	0	0	0	4
Acronicta ovata (Grt.)	17 Jun - 13 Aug	13 Aug	49	36	15	14	6	1	121
Acronicta haesitata (Grt.)*	09 Jul - 16 Jul	09 Jul	3	0	0	0	0	0	3
Acronicta impleta (Wlk.)	11 Jun - 11 Jun	11 Jun	0	1	0	0	0	0	1
Amphipyra pyramidoides (Gn.)	13 May - 25 Jun	14 May	30	37	0	8	3	3	81
Cosmia calami (Harv.)*	13 May - 15 Jun	21 May	33	26	2	10	0	2	73
Lithophane hemina (Grt.)	21 May - 02 Jul	11 Jun	0	7	0	0	0	0	7
Lithophane querquera (Grt.)*	21 May - 21 May	21 May	0	1	0	0	0	0	1

Species*	Collection Dates		Peak	T90	C90	T91	C91	T92	C92	Total
	First	Last								
Lithophane antennata (Wlk.)*	13 May -	08 Jun	01 Jun	7	3	0	5	3	5	23
Lithophane laticinerea (Grt.)*	29 May -	29 May	29 May	0	2	0	0	0	0	2
Lithophane grotei (Riley)	07 Jul -	07 Jul	07 Jul	0	0	0	0	1	0	1
Lithophane unimoda (Lint.)*	14 May -	14 May	14 May	1	0	0	0	0	0	1
Eupsilia sidus (Gn.)*	21 May -	11 Jun	04 Jun	2	2	0	0	0	0	4
Eupsilia n. sp.*	14 May -	11 Jun	18 May	11	17	5	14	2	9	58
Eupsilia morrisoni (Grt.)	14 May -	29 May	14 May	8	11	0	0	0	0	19
Eutolype rolandi (Grt.)*	21 May -	29 May	21 May	0	1	0	0	0	0	1
Copipanolis styracis (Gn.)*	13 May -	01 Jun	21 May	2	6	0	2	0	1	11
Psaphida resumens (Wlk.)*	13 May -	11 Jun	29 May	8	7	0	2	0	0	17
Psaphida thaxteriana (Grt.)*	14 May -	14 May	14 May	1	1	0	0	0	0	2
Polia latex (Gn.)	03 Jun -	13 Aug	09 Jul	14	19	7	11	4	5	60
Orthosia rubescens (Wlk.)	20 May -	08 Jun	21 May	4	2	0	1	0	1	8
Orthosia revicta (Morr.)*	01 Jun -	01 Jun	01 Jun	0	0	0	0	1	0	1
Orthosia alurina (Sm.)*	14 May -	22 Jun	29 May	4	6	0	0	1	0	11
Orthosia hibisci (Gn.)	13 May -	29 Jun	21 May	59	112	5	42	7	15	240
Himella intractata (Morr.)	14 May -	11 Jun	04 Jun	1	2	0	1	0	1	5
Achatia distincta (Hbn.)	29 May -	07 Jul	29 May	0	3	0	0	1	1	5
Morrisonia confusa (Hbn.)	20 May -	13 Aug	20 Jul	25	16	13	11	29	19	113

* Species not collected as larvae at Coopers Rock State Forest (Butler 1992).

Species were primarily Noctuidae (39 species) and Geometridae (27 species). The most abundant macrolepidoptera larvae during the study were the Geometridae *Phigalia titea* (Cram.), P. *strigataria* (Minot) and *Erannis tiliaria* (Harr.); the Saturniidae *Anisota senatoria* (J.E. Smith) and A. *virginiensis* (Drury); the Notodontidae *Nadata gibbosa* (J.E. Smith) and the Noctuidae *Orthosia hibisci* (Gn.), *Acronicta ovata* Grt., *Morrisonia confusa* (Hbn.), *Polia latex* (Gn.) and *Amphipyra pyramidoides* Gn. Several of these species, most especially the early season geometrids and noctuids declined on the *Btk*-treated plots. Abundance for many of these species was higher on untreated plots in the pretreatment year as well.

Dates of first collection and last collection for the larvae represent limitations of foliage sampling effort over the seasons. Sampling began the second week of May (May 13) soon after leaf expansion of oak began on the plots, and ended in mid-August each year. Larval species that were feeding on oaks on the plots before or after these sampling periods were not represented.

In addition to 10 families of macrolepidoptera larvae found on the oak foliage, 190 other taxa (primarily families) were identified (Table 3). The most abundant families were Aphididae, Curculionidae, Tenthredinidae, Pergidae, Coccidae, Cicadellidae, Reduviidae, Miridae, Formicidae and Elateridae. All are herbivores with the exception of the predatory reduviids and the omnivorous formicids. The numbers of Aphididae fluctuated from high levels in 1991 to relatively low in 1990 and 1992. A similar pattern was noted for the Coccidae, Cicadellidae and Miridae, all plant juice feeders. The chewing herbivores Curculionidae, Tenthredinidae and Pergidae were highest on all plots in 1990 and 1991 and declined in 1992.

The Membracidae were relatively more abundant on all plots in 1991 and 1992 and the Gelechiidae, Linyphiidae, Tortricidae, Chrysomelidae and Philodromidae were in relatively higher numbers on all plots in 1990 and 1991. Families whose numbers remained relatively stable over the three years included Salticidae, Araneidae, Thomiscidae and Dictynidae, all spiders.

Possible effects as related to *Bacillus thuringiensis* application or gypsy moth defoliation in the absence of insecticide treatment were seen for the Aphididae, Pergidae and Tingidae, herbivores which compete with gypsy moth for food and which are presumably not sensitive to *Btk*. In the treatment year (1991) numbers for these three families were 44 to 85% higher on the *Btk*-treated plots. The microlepidoptera families Gelechiidae and Tortricidae were in higher numbers on the control plots during the treatment year but numbers also had been higher on the control plots in the pretreatment year. As a general trend, macrolepidoptera larval numbers for most species were highest in 1990 and declined each year of the study regardless of treatment. Any patterns of increase or decrease in abundance of other arthropod taxa are difficult to discern.

We note that significant differences in temperature and precipitation occurred among the study years; while 1991 was the warmest year during the sampling period and 1992 the coolest, the greatest rainfall occurred in 1990 and in 1992. The treatment year therefore was the warmest and dryest during the three-year study.

Table 3: Non-macrolepidoptera taxa taken from foliage of mixed oak species: abundance on treated (T) and control (C) plots and total number for the study. Taxa are arranged from most to least abundant.

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Aphididae	11	181	1437	805	157	147	2738
Curculionidae	336	345	232	307	63	63	1346
Tenthredinidae	537	445	177	143	6	3	1311
Pergidae	179	305	538	177	12	9	1220
Coccidae	12	81	571	528	0	4	1196
Cicadellidae	29	39	363	331	106	92	960
Reduviidae	144	130	279	284	33	37	907
Miridae	51	36	267	229	106	131	820
Formicidae	108	173	114	163	91	87	736
Elateridae	71	79	213	207	71	92	733
Membracidae	32	49	126	169	127	147	650
Linyphiidae	182	178	119	116	0	5	600
Gelechiidae	146	176	82	150	9	6	569
Tingidae	68	17	334	49	15	2	485
Tortricidae	86	127	62	132	18	20	445
Salticidae	49	55	75	159	59	43	440
Chrysomelidae	83	99	50	56	13	25	326
Philodromidae	69	55	82	79	7	7	299
Phalangida	59	88	66	46	15	23	297
Araneidae	57	54	56	56	38	23	284
Thomisidae	48	31	43	44	51	37	254
Theridiidae	36	24	88	90	0	5	243
Cercopidae	14	11	89	67	24	21	226
Dictynidae	30	31	62	42	35	21	221
Polypsocidae	30	13	62	19	29	15	168
Psocidae	8	2	47	66	22	22	167
Cantharidae	31	51	15	28	9	11	145

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Micryphantidae	31	42	30	11	18	13	145
Pentatomidae	21	22	29	34	10	28	144
Coccinellidae	6	14	38	31	25	27	141
Phlaeothripidae	0	2	47	48	18	24	139
Clubionidae	29	21	7	6	38	30	131
Mordellidae	34	23	23	18	16	14	128
Scarabaeidae	8	12	24	55	19	9	127
Cecidomyiidae	1	3	28	70	3	3	108
Braconidae	19	20	23	11	20	13	106
Anyphaenidae	0	0	65	24	12	3	104
Gryllidae	8	14	39	27	8	6	102
Chalcidoidea	6	23	8	22	19	21	99
Tipulidae	26	51	6	6	5	3	97
Cynipidae	11	14	14	19	11	14	83
Ichneumonidae	21	33	11	7	3	6	81
Empididae	15	33	5	9	6	8	76
Alleculidae	4	18	23	19	4	7	75
Acrididae	1	3	6	2	26	31	69
Gracillariidae	3	52	2	3	4	1	65
Pisauridae	13	8	27	5	7	2	62
Chironomidae	6	5	8	12	7	23	61
Hemerobiidae	3	7	16	21	2	8	57
Heteronemiidae	6	4	15	11	5	3	44
Eriosomatidae	0	0	13	29	0	0	42
Anobiidae	2	5	8	13	2	11	41
Tettigoniidae	9	7	5	8	6	5	40
Proctotrupoidea	15	11	5	3	0	2	36
Melyridae	1	0	2	6	16	10	35
Dolichopodidae	8	10	2	6	3	5	34
Limacodidae	2	2	8	15	3	4	34
Cerambycidae	6	9	3	4	1	9	32

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Lauxaniidae	7	19	3	1	0	0	30
Sciaridae	7	13	1	3	1	1	26
Cleridae	2	3	6	5	1	7	24
Mycetophilidae	3	10	0	3	3	5	24
Anthicidae	8	5	6	0	2	2	23
Nemouridae	4	14	0	0	2	3	23
Buprestidae	2	2	7	3	5	3	22
Lyonetiidae	0	4	7	11	0	0	22
Staphylinidae	2	2	3	2	5	7	21
Rhagionidae	9	7	1	1	0	1	19
Anystidae	1	0	7	10	1	0	19
Lycidae	3	7	2	3	1	2	18
Psyllidae	0	1	1	0	8	7	17
Lygaeidae	2	12	1	2	0	0	17
Chrysopidae	0	4	4	4	2	2	16
Syrphidae	4	5	2	3	1	0	15
Dascillidae	7	4	1	1	0	0	14
Agromyzidae	0	0	0	0	6	8	14
Dictyopharidae	5	7	0	0	0	1	13
Coniopterygidae	1	1	3	5	2	1	13
Xyelidae	0	12	0	0	0	0	12
Mycetophagidae	0	0	2	2	5	2	11
Ptilodactylidae	4	4	2	1	0	0	11
Entomobryidae	1	1	3	0	4	2	11
Lampyridae	0	0	6	1	1	2	10
Pedilidae	2	8	0	0	0	0	10
Drosophilidae	0	3	2	4	0	1	10
Siricidae	4	6	0	0	0	0	10
Leuctridae	0	0	5	3	2	0	10
Oedemeridae	1	7	0	0	1	0	9
Lathridiidae	2	2	2	2	0	0	8

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Muscidae	2	4	0	2	0	0	8
Pyralidae	4	3	0	1	0	0	8
Chloroperlidae	1	3	2	1	1	0	8
Cicadidae	0	0	0	0	1	6	7
Coreidae	1	2	1	1	2	0	7
Scolytidae	0	0	1	0	4	1	6
Tachinidae	0	1	0	3	2	0	6
Derbidae	3	2	0	1	0	0	6
Lagriidae	1	1	3	0	0	0	5
Cryptophagidae	0	0	0	0	0	5	5
Stratiomyidae	2	1	0	2	0	0	5
Chloropidae	0	1	0	2	1	1	5
Calliphoridae	1	1	0	3	0	0	5
Tabanidae	1	0	1	1	1	1	5
Achilidae	1	1	2	1	0	0	5
Issidae	5	0	0	0	0	0	5
Thripidae	0	1	2	2	0	0	5
Byrrhidae	1	3	0	0	0	0	4
Phoridae	3	1	0	0	0	0	4
Asilidae	3	0	0	0	1	0	4
Anthophoridae	0	0	1	0	0	3	4
Trombidia	1	0	1	0	1	1	4
Tineidae	2	2	0	0	0	0	4
Perlodidae	0	1	1	0	1	1	4
Aeolothripidae	0	0	0	3	1	0	4
Colydiidae	0	0	1	0	2	0	3
Anthomyiidae	0	1	1	1	0	0	3
Bibionidae	0	2	0	1	0	0	3
Cixiidae	1	0	1	0	0	1	3
Delphacidae	0	3	0	0	0	0	3
Phylloxeridae	1	0	0	1	0	1	3

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Mantispidae	0	1	1	1	0	0	3
Hypogastruridae	3	0	0	0	0	0	3
Uloboridae	0	0	3	0	0	0	3
Ixodidae	1	2	0	0	0	0	3
Baetidae	1	1	0	1	0	0	3
Perlidae	2	0	0	0	1	0	3
Tenebrionidae	0	0	1	1	0	0	2
Pyrochroidae	0	2	0	0	0	0	2
Salpingidae	0	0	0	1	1	0	2
Lonchopteridae	0	0	0	2	0	0	2
Acroceridae	0	0	2	0	0	0	2
Chamaemyiidae	0	1	0	1	0	0	2
Halictidae	0	0	2	0	0	0	2
Sphecidae	1	0	1	0	0	0	2
Colletidae	0	1	0	0	1	0	2
Pamphiliidae	1	0	1	0	0	0	2
Nabidae	0	0	2	0	0	0	2
Alydidae	0	0	2	0	0	0	2
Rhopalidae	0	0	2	0	0	0	2
Corydalidae	1	1	0	0	0	0	2
Sminthuridae	0	0	2	0	0	0	2
Tetragnathidae	2	0	0	0	0	0	2
Cossidae	0	0	0	0	2	0	2
Heptageniidae	0	0	1	1	0	0	2
Gryllacrididae	0	0	0	2	0	0	2
Panorpidae	0	0	0	0	1	1	2
Machilidae	2	0	0	0	0	0	2
Diplopoda	0	0	0	0	0	2	2
Forficulidae	0	0	0	2	0	0	2
Nitidulidae	0	0	0	1	0	0	1
Erotylidae	1	0	0	0	0	0	1

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Endomychidae	1	0	0	0	0	0	1
Bruchidae	0	1	0	0	0	0	1
Cicindelidae	0	0	0	0	1	0	1
Lyctidae	0	0	0	1	0	0	1
Simuliidae	0	0	0	1	0	0	1
Ceratopogonidae	0	0	1	0	0	0	1
Psychodidae	0	1	0	0	0	0	1
Pipinculidae	1	0	0	0	0	0	1
Culicidae	1	0	0	0	0	0	1
Sciomyzidae	1	0	0	0	0	0	1
Xylophagidae	1	0	0	0	0	0	1
Xylomyidae	0	0	0	0	0	1	1
Leptogastridae	0	0	0	0	0	1	1
Piophilidae	1	0	0	0	0	0	1
Milichiidae	0	0	0	1	0	0	1
Platygasteridae	0	1	0	0	0	0	1
Vespidae	0	0	0	0	1	0	1
Apidae	1	0	0	0	0	0	1
Bethylidae	0	0	1	0	0	0	1
Argidae	1	0	0	0	0	0	1
Cimbicidae	0	0	0	0	1	0	1
Diprionidae	0	0	0	0	1	0	1
Aulacidae	1	0	0	0	0	0	1
Tiphiidae	0	0	0	0	1	0	1
Pompilidae	0	0	0	0	1	0	1
Andrenidae	0	0	0	1	0	0	1
Dilaridae	0	0	1	0	0	0	1
Hydropsychidae	1	0	0	0	0	0	1
Goeridae	1	0	0	0	0	0	1
Amaurobiidae	0	0	0	1	0	0	1
Agelenidae	0	0	1	0	0	0	1

Taxon	T90	C90	T91	C91	T92	C92	TOTAL
Lycosidae	0	0	1	0	0	0	1
Acarina	0	0	0	0	1	0	1
Oribatidae	0	0	0	1	0	0	1
Oecophoridae	0	0	0	1	0	0	1
Eriocraniidae	0	1	0	0	0	0	1
Plutellidae	0	1	0	0	0	0	1
Tetrigidae	0	0	1	0	0	0	1

Discussion

The collection of 91 species of macrolepidoptera larvae on foliage of mixed oaks in West Virginia's Eastern Ridge and Valley Section compares favorably with results of an earlier study by Butler (1992) at Coopers Rock State Forest in the Allegheny Mountain and Upland section of West Virginia. In the earlier study at Coopers Rock State Forest, foliage sampling was conducted for black birch, black cherry, red maple and mixed oaks for a total larval richness of 100 species. Sixty-one of those 100 species were taken on mixed oaks, only 15 of the 61 species being exclusively on oak. The earlier study was conducted for only two years instead of three as in the current study, and the sampling intensity each week from mid-May to mid-August was less on the earlier study. However, in the earlier study, foliage sampling was continued each year until the beginning of leaf fall in October.

Caterpillar species taken during the current study which were not collected as larvae in the 1992 Coopers Rock study include 7 species of geometrids, a lasiocampid, a nymphalid, two saturniids, a notodontid and 22 species of noctuids; these are indicated by an asterisk in Table 2. Of these species, all have been taken as adults (Butler and Kondo 1991; 1993) or as larvae (Butler and Kondo 1993) in other studies at Coopers Rock or nearby in other areas of Monongalia and Preston counties, West Virginia (Butler, unpublished data). The exception would be *Hemileuca maia* (Drury), a species considered to be more common in the drier oak-pine forests of West Virginia. Some of the species not taken as larvae at Coopers Rock (Butler 1992) were likely in relatively low numbers and would have had a better chance of being represented in collections at higher sampling intensity.

Macrolepidoptera larvae taken at Coopers Rock (Butler and Kondo 1991) not taken in the *Bt* study were the papilionid *Papilio glaucus* L.; the geometrids *Itame pustularia* (Gn.), *Glena cribrataria* (Gn.), *Ectropis crepuscularia* (D. and S.), *Lomographa glomeraria* (Grt.), *Probole amicaria* (H.S.) and *Nemoria mimosaria* (Gn.); the saturniid *Actias luna* (L.); the sphingid, *Paonias myops* (J.E. Smith); the notodontids *Furcula borealis* (Guer. - Meneville), *Symmerista leucitys* Franc. and *Oligocentria lignicolor* (Wlk.); the arctiid *Lophocampa caryae* Harr.; and the noctuids *Acronicta americana* (Harr.), *A. fragilis* (Gn.), *A. increta* Morr. and *A. inclara* Sm. Most of these species do not commonly utilize oak as a host and/or are not often found in high numbers.

During this study, total Lepidoptera richness and abundance and richness and abundance of geometrids and noctuids significantly declined on treated plots during the *Btk* application year of 1991 (Sample et al. 1995). Numbers of individual species were too low for statistical analyses; however, trends may be noted. The *Btk* treatments were made 8 and 10 May 1991. Nontarget larvae on plots at that time and soon thereafter appeared to decline. Included were the Geometridae *Hypagyrtis unipunctata* (Haw.), *Phigalia titea*, *Phigalia strigataria*; and *Erannis tiliaria*; and noctuids *Amphipyra pyramidoides*, *Cosmia calami* (Harv.), *Lithophane antennata* (Wlk.) and *Orthosia hibisci*. Other early spring species were in such low numbers as to obscure any trends. No difference was noted between numbers of these species on treated and nontreated plots in 1992, the post-treatment year, again in part because of very low numbers of nontarget caterpillars on all plots in that year.

Caterpillar species which were collected in relatively high numbers beginning late May and for the remainder of the season did not appear to be affected by the *Btk* application. Included were the geometrid *Besma endropiaria* (G. & R.), the saturniid *Anisota virginiensis*, the notodontid *Nadata gibbosa*, the arctiid *Hyphantria cunea* (Drury) and the noctuids *Acronicta ovata*, *Polia latex*, and *Morrisonia confusa*. *Btk* is known to persist only for a few days on treated foliage (Sundaram and Sundaram 1992).

Since larval numbers declined each year of the study on all plots, factors other than *Btk* effect must have been responsible. High abundance of predators, parasitoids or diseases may have been responsible for the declines on all plots in 1991 and 1992, but we have no data to support the role of these biotic factors. Weather is another logical possibility. Since we have no data from the plots prior to 1990, we can see no trends which may have led to the relatively high numbers of nontarget caterpillars on the plots in 1990. Perhaps populations of macrolepidoptera were already declining in 1990 and continued that pattern in later years of the study. Numerous studies have been conducted on direct and indirect effects of weather trends and atypical catastrophic temperature and rain events on insect populations (Martinat 1987). Since 1991 showed the highest mean temperatures and lowest mean rainfall for the April through August period during the three years, we may have expected stable or increasing numbers of some lepidopterous larvae. This would be supported by White (1974) who showed outbreaks of loopers (spring defoliating geometrids) related to drought conditions which stressed host trees and Ives (1973) who related collapses of the forest tent caterpillar, *Malacosoma disstria* Hbn., to cool springs.

During 1992, macrolepidoptera populations continued to decline on all plots. While mean temperature for April through August that year was the lowest of the three years, mean precipitation was the same for 1992 and 1990. Low spring temperatures have been shown to produce collapse in populations of some caterpillars (Ives 1973).

Among the non-macrolepidopterous taxa taken during the study, the Aphididae were considerably higher on all plots during 1991 than the other years. High temperatures and low rainfall are known to trigger outbreaks in aphid populations (Jones 1979). During 1991 of the *Btk* study there were much higher numbers of other juice-feeding insects (Coccidae, Cicadellidae and Miridae) on all plots. Drought stress to plants which benefits aphids also may benefit aphid relatives in the same feeding guild.

Through the use of the foliage pruning method with a plastic catch bag we may have lost some of the more active arthropods from the foliage, particularly certain Hymenoptera and Diptera. Thus, we suspect that richness and abundance of arthropods on foliage was higher than we determined, but this loss was presumably consistent for all samples.

Among the chewing herbivores including Curculionidae, Tenthredinidae, Pergidae, Gelechiidae, Tortricidae and Chrysomelidae, lowest numbers were found in 1992, the same year that the macrolepidopterous larvae in the same feeding guild declined so dramatically. Perhaps the same factors are responsible for decline of all groups. Again, direct effects of weather or indirect effects as mediated through the host plants would be implicated since biotic factors such as parasitoids and diseases may not be expected to affect such divergent groups of herbivores.

Summary

Diverse macrolepidopterous larval species and arthropod family taxa were found in the oak canopy in West Virginia's Eastern Ridge and Valley Section. Many species and families were represented by very low numbers.

Bacillus thurinigiensis kurstaki produced signficiant decline of macrolepidopterous larvae on treated plots during the treatment year (Sample et al. 1995). We have shown in the paper that the decline occurred in those caterpillar species that were in the oak canopy at the time of *Btk* application or soon thereafter. There appeared to be no difference in abundance on treatment and control plots for those caterpillar species occurring in mid- and late-season, i.e. some weeks or months post-treatment. No difference between treated and control plots was shown in abundance for most species in 1992, the post-treatment year; an exception was the early spring defoliator, *Alsophila pometaria*. However, this species had been more abundant on the untreated plots prior to *Btk* application. Non-Lepidoptera appeared to suffer no negative effect from the *Btk* treatment.

Abundance and richness of nontarget macrolepidopterous larvae declined each year of the three year study, even on non-treated plots. Other families of chewing herbivores were in very low abundance also by 1992. Weather related effects may be responsible for this decline.

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